Feature

Sun clocks in as migration key

The mechanisms by which some animals are able to achieve astonishing feats of migration have often eluded researchers because of the difficulty of designing suitable experiments. Two Canadian researchers believe they now have a set-up to throw light on the flight of the monarch butterfly. **Nigel Williams** reports.

The striking monarch butterfly, known to millions of north Americans as it travels thousands of miles from its winter roosting grounds in central Mexico to its breeding sites in central and eastern north America, has intrigued researchers. Even more startling is the autumn return of subsequent generations to Mexico which have never known their winter home. Now two researchers in Ontario believe they have come up with an experimental set-up that throws key light on how the butterflies manage these extraordinary journeys.

For an insect that weighs no more than half a gram, the effort of flying thousands of miles is in itself remarkable. Scientists are used to recording feats of migratory behaviour in animals, but for its size the yearly migration of the monarch is perhaps the most spectacular. What is equally amazing is that the return journey to Mexico is made by adults which were born that summer in the US and Canada, making them completely naïve travellers who make the return leg of the journey unaccompanied by other experienced individuals.

It is clear, therefore, that whatever the mechanism monarchs use to migrate so far without losing their way, it must genetically imprinted. Some other species of butterfly can make similar long journeys in search of food but they only travel one way, which is strictly emigration rather than migration. For example, two of northern Europe's largest and most colourful butterflies, the red admiral (*Vanessa atalanta*) and the painted lady (*Cynthia cardui*) originate from populations around the Mediterranean and, although they can breed in northern Europe during the summer, few survive the cold, wet winters and they have not evolved a mechanism to get them back to the Mediterranean. What makes the monarchs' behaviour so unique is that not only do they return to the winter roosts in Mexico but they find the sites used by their great-great-grandparents the winter before, and often return to precisely the same location, even to the tree used by their ancestors.

As the days begin to shorten in late summer and the nights become cooler, changes are triggered in the monarchs emerging from their chrysalides at that time of year. Although the butterflies look like other early and mid-summer adults, they will not mate or lay eggs until the following spring. Being unable to survive the cold winter, they have evolved the ability to fly south before daytime temperatures fall too low for the flight muscles of their cold-blooded bodies.

Although they have fat stored in their abdomen, monarchs help to fuel their trip by feeding on the nectar of flowers they encounter on their journey south. Small groups of monarchs, which are usually solitary, begin to congregate at night. Spectacular orange and black bunches of monarchs eventually arrive to roost on the branches of the oyamel trees which grow in a narrow belt across a few mountain tops in central Mexico.

Henrick Mouritsen, a researcher at Queen's University, Ontario, working with his colleague, Barrie Frost, have come closer than anyone else to explaining how the monarch manages this spectacular journey. They have constructed an apparatus that acts as a butterfly flight simulator. And they believe the results show that the monarchs use a Sun compass to find their way, and that they compensate for the movement of the Sun during the day with an accurate body clock for telling the time.

Mouritsen and Frost captured 59 wild monarchs as they began their journey south and tethered them by their thoraces using a beeswax glue to thin tungsten wires. This enabled the insects to be suspended in a gentle wind tunnel – a sort of butterfly flight simulator. The procedure was harmless and the butterflies were released into the wild at the end of the experiment. With the help of a gentle updraft,the monarchs could fly in any direction of their choice – a low friction bearing in a joint in their tether allowed the butterflies to turn easily whenever they wanted.

When the butterflies were taken outside in opaque tubes with only the Sun visible, they consistently flew in the same south-westerly direction that they would have flown naturally in the region of Ontario where they were captured. Even when the scientists tried to force the butterflies to move in a different direction by turning them round, they quickly corrected the change to resume their original path. 'We are confident that the directions chosen by the butterflies in our flight simulator are not random directions, but accurately represent the intended flight directions, because in hundreds of forced turn experiments, all butterflies immediately returned to their previous geographical heading,' the scientists write in the recent issue of the US Proceedings of the National Academy of Sciences (vol 99, no 15, p. 10162-10166) 'No matter which part of the set up was turned while a butterfly was actively migrating in the set up all the butterflies kept their

Solar power: New research suggests that monarch butterflies in North America navigate their extraordinary migration by the use of a Sun compass and an accurate biological clock, which allow butterflies to maintain a fixed migratory path towards their wintering grounds in central Mexico. (Photograph: Science Photo Library, London.)

geographical heading,' the researchers say.

The average direction in which the butterflies in the flight simulator flew – a mean orientation of 225 degrees – was in close agreement to the average 220-degree orientation monitored in wild monarchs in Ontario. It was also close to the 226 degree direction from the laboratory to the Mexican wintering grounds calculated from map bearings. The researchers were confident that the flight simulator was indeed a true reflection on wild migratory behaviour, but how to prove that it is the Sun that is the key to the monarch's orientation?

To confirm the Sun-compass theory, the researchers needed to know how how the insects coped with an object that moved across the sky during daylight hours. They therefore trained some of the monarchs to fly in artificial daylight that had been 'clock-shifted' by six hours either forward or backwards. So some of these butterflies would view the Sun's position at midday as being at where it should be at 6am and the other, late-shifted monarchs at its 6pm position. If so, then then each group should fly in completely different directions. Indeed, each set of these clock-shifted butterflies flew at 90 degrees to either the right or left of the direction they should have been flying depending on whether their biological clocks had been advanced or delayed.

'The clear and predicted directional shifts produced by clock-shifting the butterflies provide strong evidence that migratory monarchs use a time-compensated Sun compass,' the researchers say. A final issue, though, still had to be addressed. Some scientists in a previous study had found that monarchs seemed to be able to use a compass that was sensitive to the invisible magnetic fields of the Earth. But the claims did not hold up and the findings were subsequently retracted.

But just to make sure that there was not something else influencing the monarch's flight, Mouritsen and Frost moved their experiments indoors under dispersed artificial light to simulate very cloudy weather. They subjected the insects to artificial magnetic fields that were rotated in a different direction. Yet the monarchs flew in random directions showing that there was no evidence of a magnetic compass. 'Because the lack of magnetic orientation occurred in exactly the same apparatus where the butterflies showed clear time-compensated Sun compass orientation, this negative result becomes particularly important,' the researchers say.

While this may provide an insight into the butterflies' international travel, it remains unclear how, arriving on their compass bearing to Mexico, they are then able to find the specific roosting trees of their ancestors.